Submillimetre Observations of Debris Disks

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the point of it

- submillimetre imaging of debris disks can tell us about:
  - outer bounds of planetary systems

    e.g. compared to disks around protostars
  - any ‘missing’ disk population

    i.e. cold disks
  - large structures related to planets on large orbits (beyond Neptune...)

what's observed

- submm observations pick up the thermal emission from cold dust grains
  - modelling the SED shows the grains are a few microns up to centimetres (or more) in size
  - grains should have fallen in the star due to drag forces... evidence of colliding comets
  - signal is optically thin (so traces mass) and is >> the photosphere (minimal calibration errors)

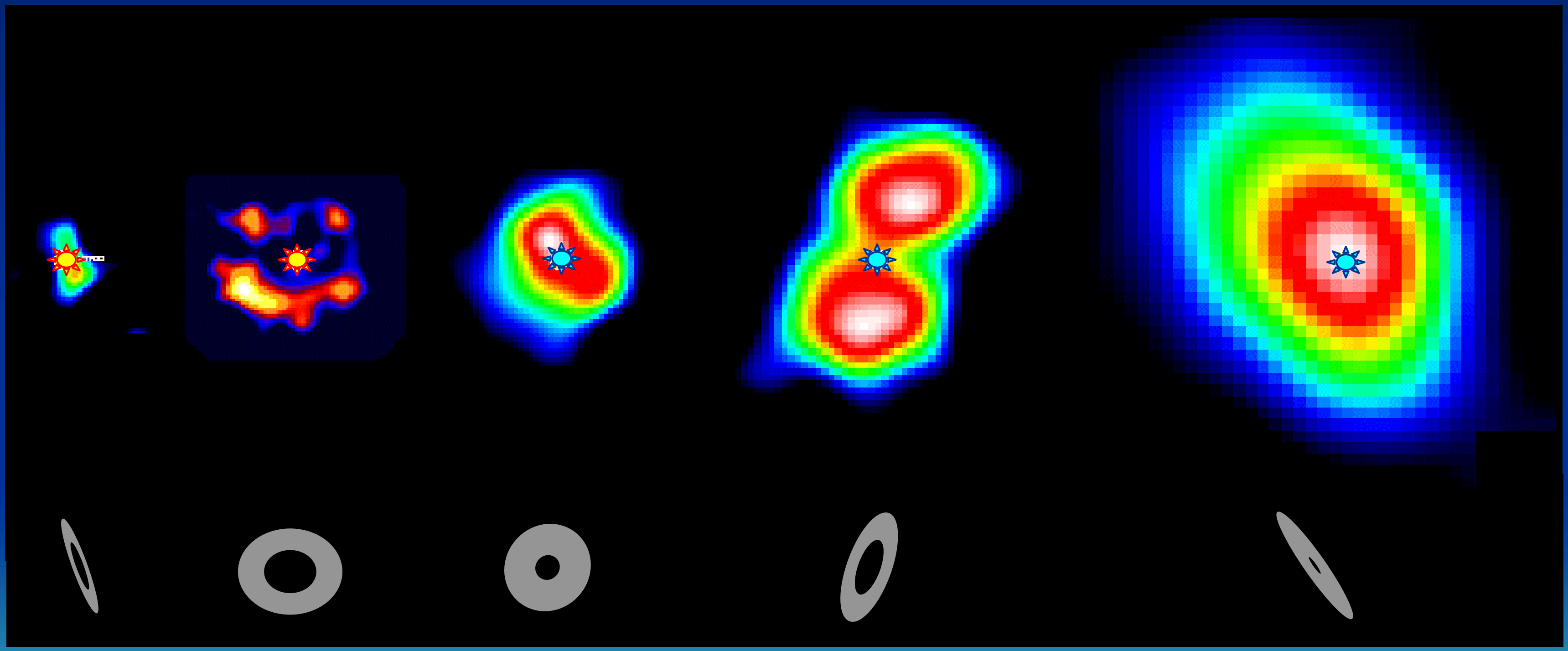
- e.g. SCUBA: observes at 450 and 850 μm wavelengths simultaneously
  - beam size = 8-15’’
- sensitive to mJy fluxes... but still need to observe for tens of hours to get deep images
  - especially at 450 μm

(1) Outer Bounds

- observing with 8-15'' beams limits us to nearby stars... but it's the only way to detect outer bounds of planetary systems
  - finding mostly large examples!
  - only one is as small as the Sun's Kuiper Belt, with r ~ 50 AU
- imaging is important, as fitting the SED can give significant size errors
    - see Sheret et al. (2004) on different grain models

famous examples, all to same physical scale

τ Ceti   ε Eridani   Vega (α Lyr)   Fomalhaut (α PsA)   β Pic



- there are now five examples of debris disks imaged around *Sun*-like stars

• η Corvi (F2)	r_{out} = 150 AU	t ~ 1 Gyr
• HD 107146 (G2)	r_{out} = 150 AU	t ~ 0.1 Gyr
• τ Ceti (G8)	r_{out} = 55 AU	t = 10 Gyr
• ε Eri (K2)	r_{out} = 100 AU	t = 0.85 Gyr
• AU Mic (M1)	r_{out} < 70 AU (submm)	t ~ 0.01 Gyr

- these are similar dimensions to the dense parts of ‘proto-planetary’ disks
  – bodies like Pluto may take Gyr to grow at these radii (Kenyon & Bromley 2004)

(2) Missing disks

- the submm is sensitive to *cold* disks
  - missed even by Spitzer? disk excess is small compared to the photosphere for $T_{dust} \leq 40$ K
    - very accurate calibration needed to be sure an excess is real; also the true photosphere is uncertain for K and M dwarfs
- Sun-like stars are more likely to have cold 'missed' disks
  - IRAS excesses for 60% of nearby A stars!

G-star survey

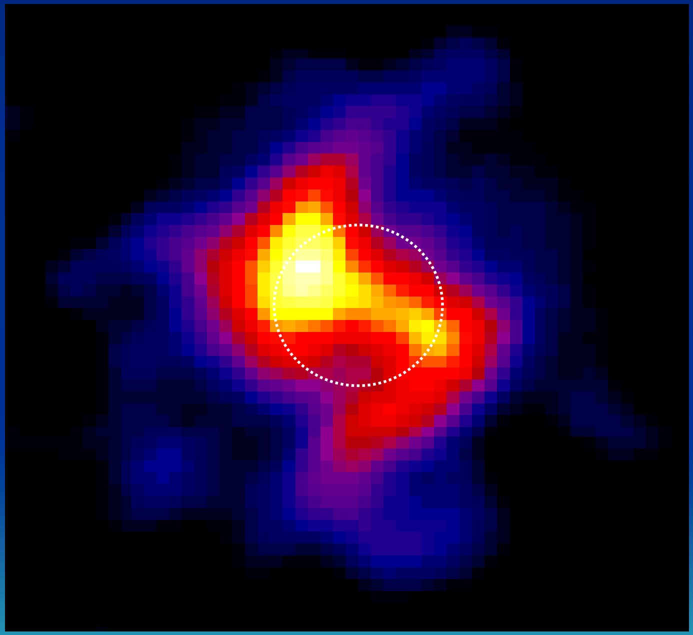
- ongoing with SCUBA... unbiased survey of G dwarfs 10-15 pc from the Sun
  - one IRAS detection confirmed
  - one to three new detections, out of 13 stars
  - one ISO source not confirmed (HD 72905)
    - unusual object... ‘superflare’ star
- if all 4 SCUBA results are real, detection rate rises to ~30%!
  - versus 7% for G stars observed with IRAS/ISO

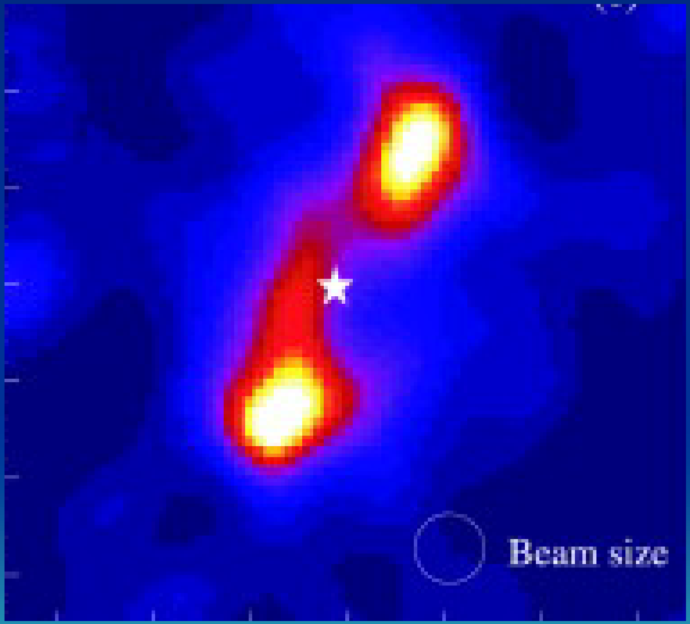
(3) Planets on large orbits

- two sorts of evidence
  - inner holes in most of the disks... dust is ejected by planets?
    - possibly just grains shrinking due to ice sublimation... but temperatures don't quite match
  - structure within the dust belts
    - if due to planets, 'lumps' should be associated with particular resonances
    - could pinpoint the planet position, in advance of imaging missions!

A stars

- Vega: planet migrated to 65 AU?
  (Mark Wyatt's talk)
- Fomalhaut: planet at ~100 AU?
  (Holland et al. 2003)





plus 1.3 mm interferometry by Koerner et al. (OVRO), Wilner et al. (PdBI)

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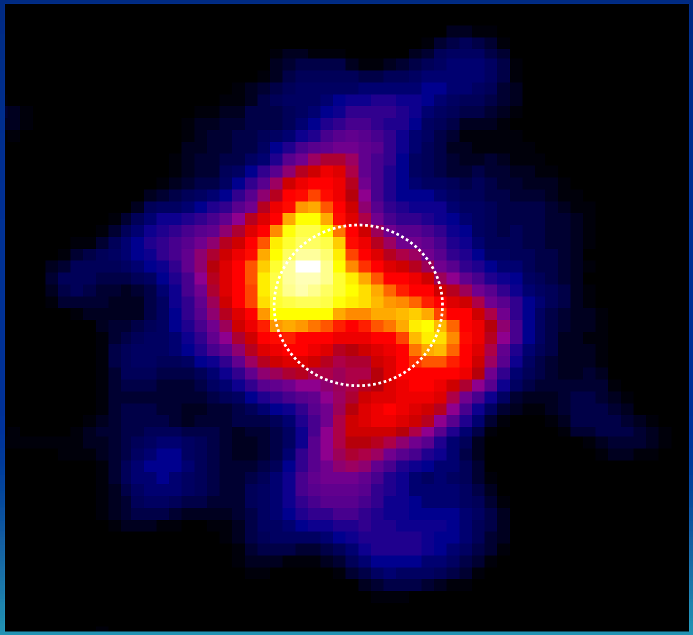

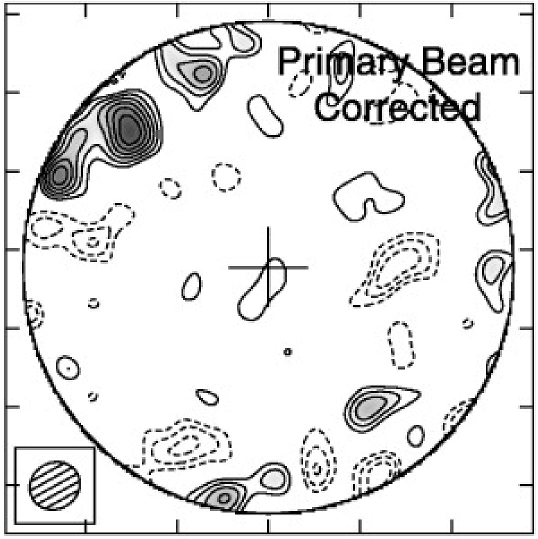

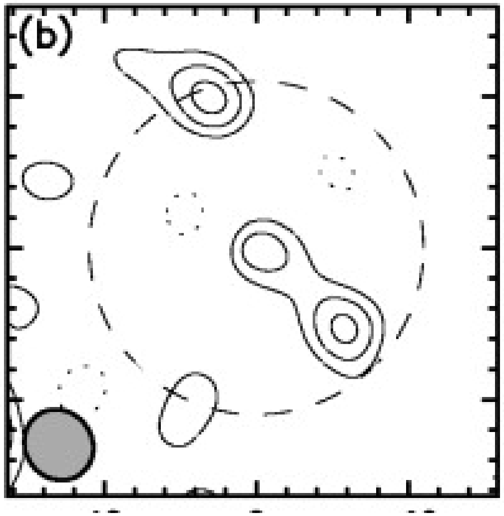

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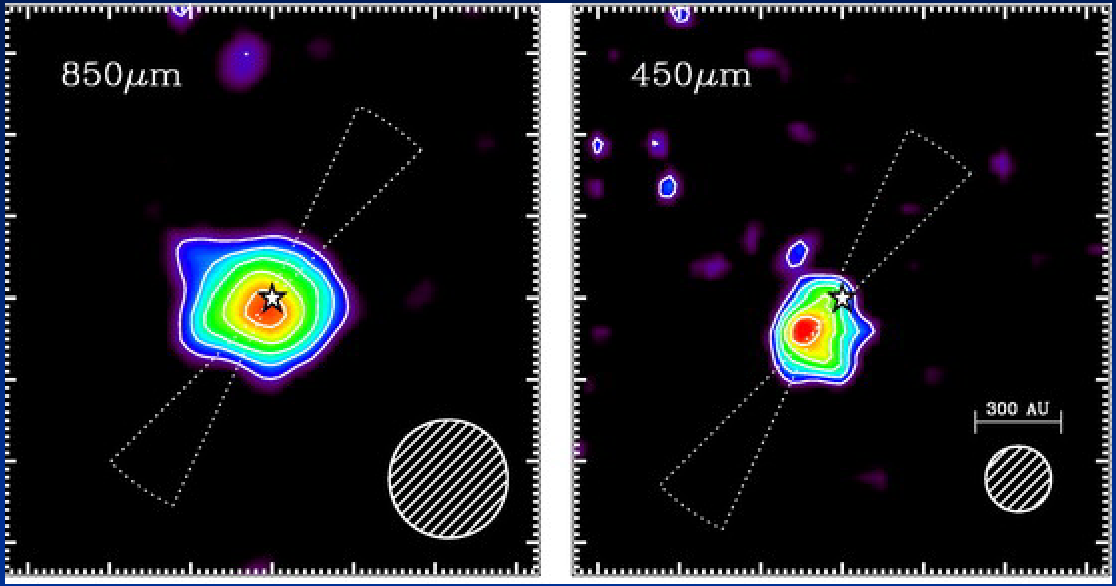
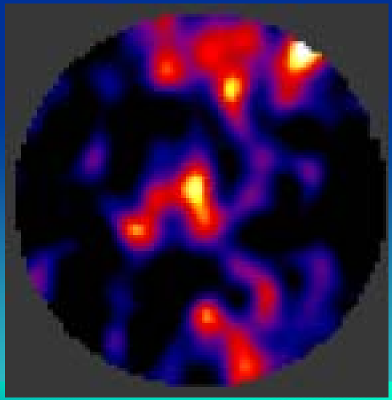
G stars

- HD 107146
  (Williams et al.)
  a young G2V
  at 28 pc



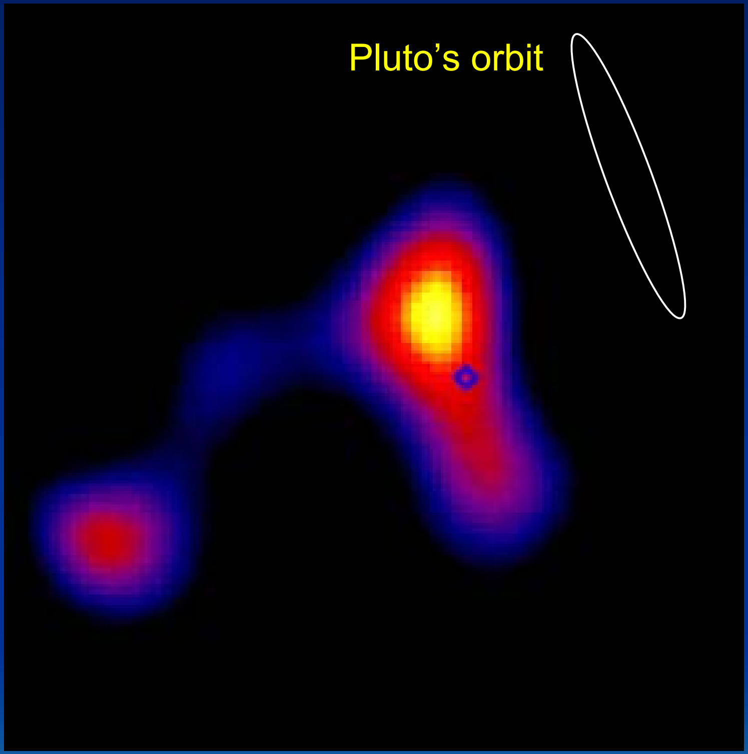
- τ Ceti (G8V)
  faintest disk so far imaged with SCUBA (5 mJy at 850 μm)



τ Ceti – Solar analogue?

τ Ceti is a G8V star, 3.65 pc away

- from VLTI, stellar radius implies age of 10 Gyr
  (di Folco et al. 2004)
- twice the Sun's age, so surprising the comets haven't all ground each other down to dust?



τ Ceti could spoil everything... :-(

- modelling the collisional cascade leads to a population of 1.2 M_{earth} in bodies up to 50 km in size (generating 5 x 10^{-4} M_{earth} in dust)

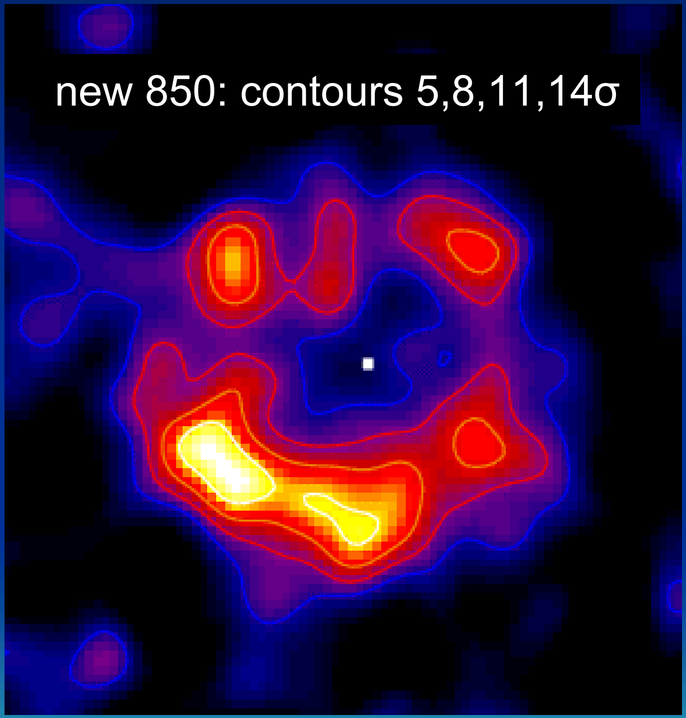
  (Greaves et al. 2004)
- the Kuiper Belt has 12-20 times less material, using comet masses or dust fluxes...
- if there are any planets around τ Ceti, might they have undergone heavy bombardment for the whole 10 Gyr?
  - *we don't know yet which of the 2 stars is 'normal'!!*

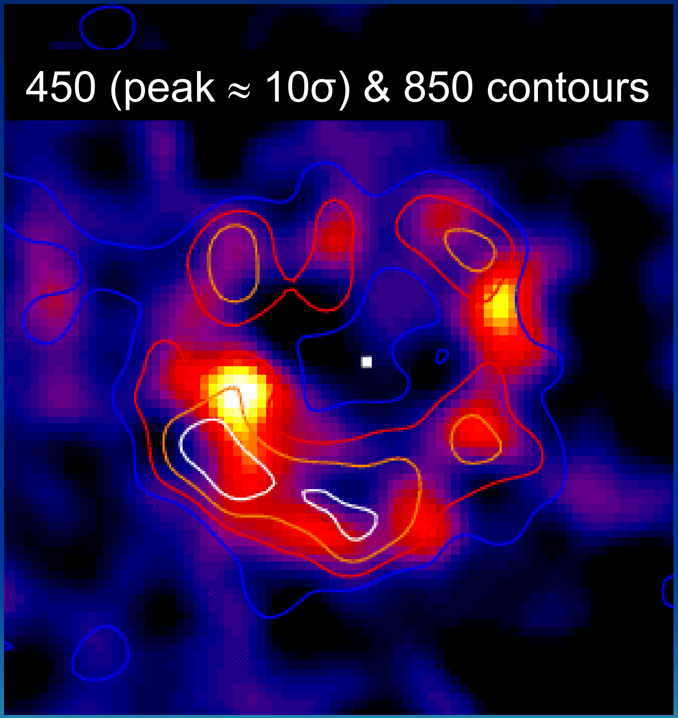
ε Eridani

- ε Eri is a K2V star, 3.22 pc away
  - thanks to the large-ish disk, we have the most detailed view of this among all the debris stars
  - we have collected SCUBA data from 1997/8 (published) up to 2002 (in prep.)
    - new data confirms the structure seen at 850 μm
    - imaged also now at 450 μm → same structure
    - see also 350 and 1200 μm images from Wilner et al. (SHARC II on CSO), Schütz et al. (SIMBA on SEST)

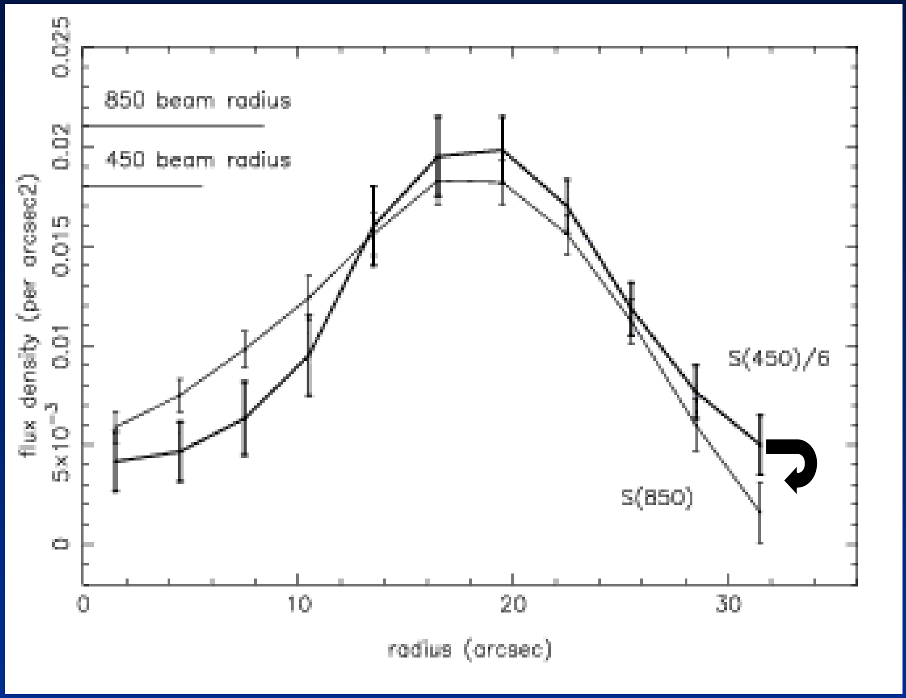
- compare the 450 and 850 micron images
  - same ring structure and similar peak locations

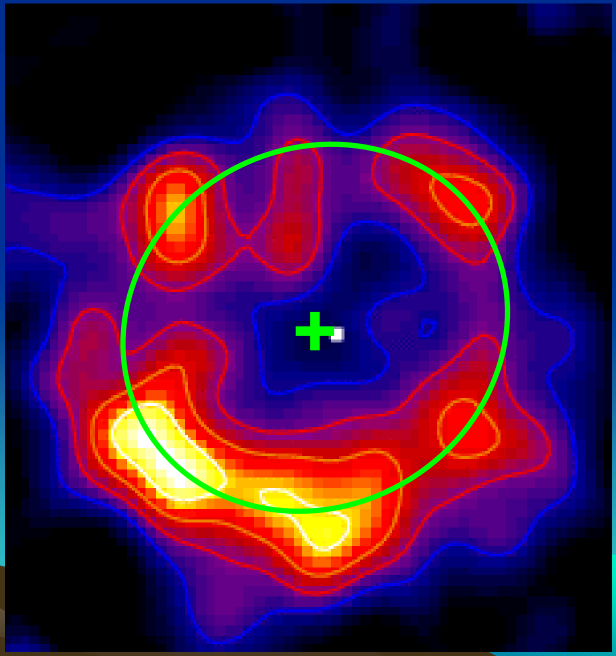
    (differ by 2-7'', consistent with expectation from noise)





- new results:
  - central beam has slightly less flux than we thought
  - centre of 850 micron emission is offset 2'' from the star
  - could this be due to the inner planet at ~3.5 AU?
    - can force eccentricity to the dust orbits (Wyatt et al. 1999)

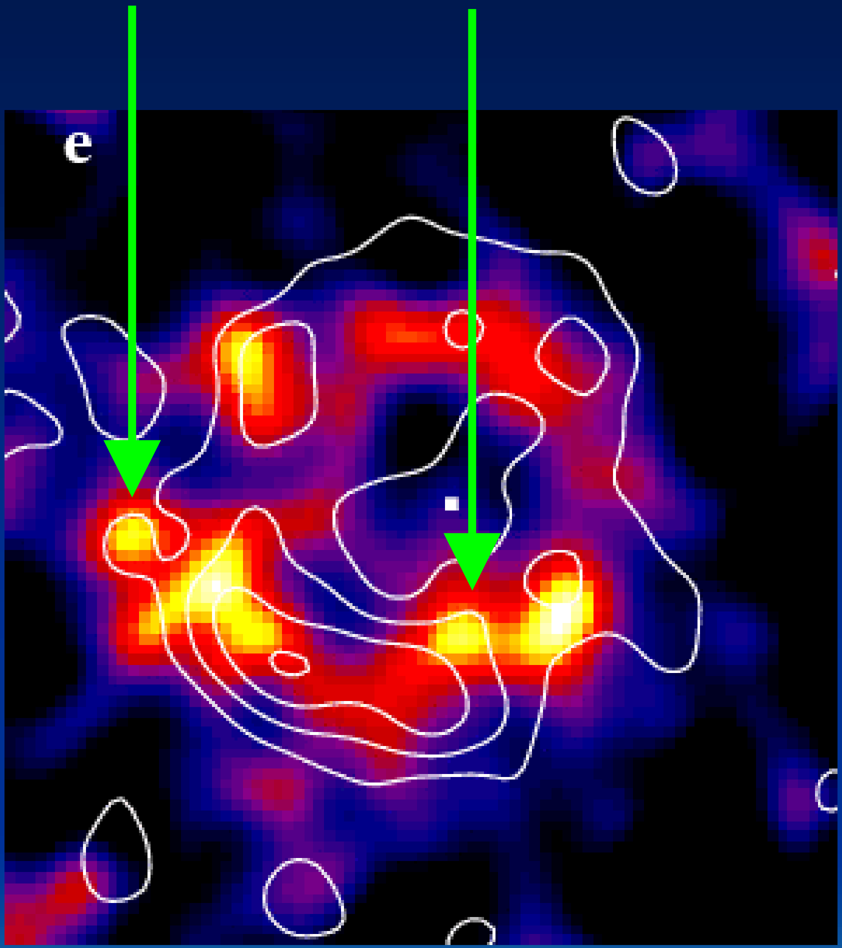




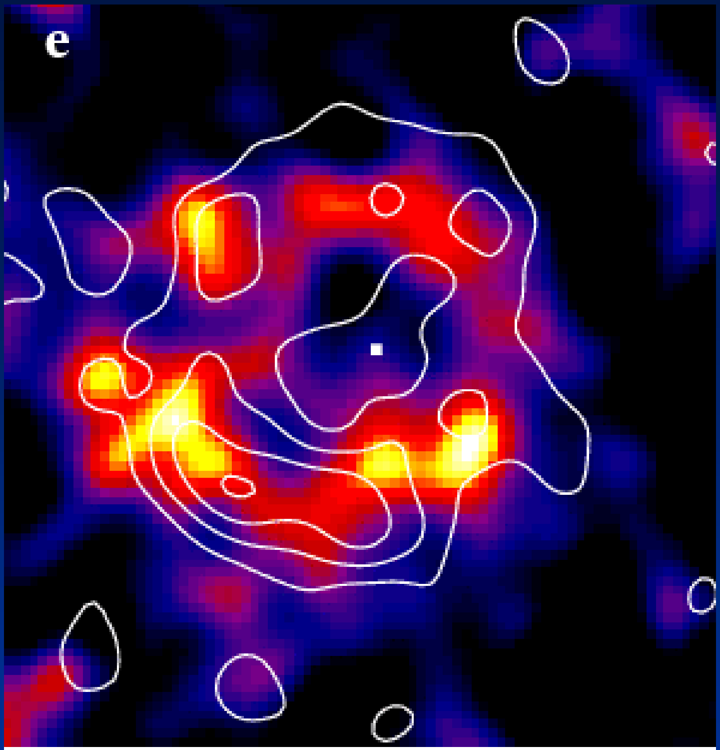
- the long time-line lets us try two things:
  - check for background sources, because the star has moved 5'' to the right (proper motion)
  - make a first attempt at looking for rotation of the ring features
    - this is going to be *TENTATIVE*, because the suspected outer planet is at ~40-60 AU, and resonant points in the ring should rotate at only ~1° per year
    - hence we looked for a consistent shift of *several* major ring features

- background objects?
  - compare the image from the 1997/8 data

    and the contour from the 2000-2002 data
  - arrows mark two lumps that *haven't* shifted to the right



- ring rotation??
  - looking for clumps that have shifted with proper motion *and* rotated around... this gives different shifts around the ring
  - tentative evidence of counter-clockwise rotation at 1-2° per year?



shaded – old clump positions
unfilled – new positions

Summary

- the comet zones are larger around most of these stars than around the Sun
- we may have missed most of the debris disk population around Sun-like stars
- submillimetre imaging can really work as a method for detecting distant planets

Large Submillimetre Telescope

the future: a 30m-class telescope operating to 200 µm, with <2” beam...